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Holistic Approach For Lightweight Automotive Exhaust System Design

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Abstract - *The automotive industry is continually evolving to meet increasingly stringent regulatory standards and consumer demands for improved efficiency and performance. As a result, there is a growing emphasis on developing lightweight exhaust systems that contribute to enhanced fuel economy, reduced emissions, and optimized vehicle dynamics. This abstract presents an overview of the latest trends and advancements in the design of lightweight automotive exhaust systems.*

***Key Words*: Automotive, Exhaust System, Light weight, VAVE.**

1. INTRODUCTION

The automotive industry has undergone a transformative shift in recent years, driven by a confluence of factors such as tightening emission regulations, increasing consumer demand for fuel efficiency, and advancements in materials and manufacturing technologies. As a result, automotive engineers and designers are facing the intricate challenge of developing innovative solutions that not only meet these demanding requirements but also enhance overall vehicle performance and driving experience.

Value Engineering (VE) is a sequential and disciplined approach to evaluate the worth or usefulness of a product for the intended customer or consumers. It targets on desired functions of Product, process, service and system there by maintaining performance, aesthetics, optimum life-cycle cost, quality reliability, and safety intact. It is used when the process is applied to new product development while The Value Analysis (VA) is used when the value process is applied to existing products [1]. The Value Engineering has two dimensions worth and cost. In Indian automotive industries Value Engineering approach is not fully utilized. It's most effective approach available to identify and eliminate unnecessary costs. Its application to product design and development, specifications and practices is less well known, its effectiveness in these areas have been proven [2]. VE is a creative thinking which is applicable for exploring best alternative ways for carrying out the various factions at the optimized cost. A product or service is generally considered to have good value if that product or services has appropriate performance and cost. Value is the most cost effective way to reliably accomplish a function that will meet the user's needs, desires and expectations [3]. It should be kept in mind that increasing the value of the product/services doesn't necessarily mean increasing the cost of the product. Value can be increased by increasing the benefits/worth and reducing the resources etc. Value engineering is targeted to identify and capture the low percentage of the factors in any product that affects the greatest percentage of the cost. Value engineering does not take any decisions whether this proposal is ok or not, it just Provoke/tries to get people to think that there are different/ equivalent ways to perform the work. It attempts to minimize the design life cycle time. It's an exercise or technique which anybody can apply in a proper defined design format under the guidance of VE specialist. During World War II many industries were faced problem of material shortage, during such critical situation efforts were made by industry people to use different techniques in order to retain the function of the product by either providing the substitute to the existing material or changing the product design keeping the product performance same/improved. Further, during 1947 based upon different approaches step by step system was developed and named as" Value Analysis". In 1959 the Society of American Value Engineers (SAVE) was incorporated in Washington, D.C. for connecting the practitioners and enabling the growth of the profession. In 1977 The Indian Value Engineering Society was formed. During this period different small growing American industries have adopted VE techniques to improve their product performance, profit margins and also for enhancing their market competitive position.

We can reduce the product cost by localization of imported parts, resourcing from a different supplier, design changes. value analysis, supplier negotiations, supply chain cost review, benchmarking, competitive evaluation, alternate Manufacturing process & re-evaluate customer needs.

M/s Tata Technologies suggest approach to achieve light weight exhaust system and consideration to be taken while design exhaust system.

2. Exhaust System

Exhaust system design is an Art, which comprises of many child parts. Exhaust System require balancing of back pressure, weight and cost targets. The requirements for

quality, productivity, and cost efficiency are at level where optimization of the design and manufacturing of a product must occur in the earliest stages of conception. The time and cost spent in trial and error analysis in the design process needs to be minimized for an industry to remain competitive in our current global market.

The purpose of any Exhaust System (ES) is to reduce the engine noise, discharging the exhaust gas in a safe manner, minimizing the power train/exhaust vibration transferred to the rest of vehicle and carry the emissions from a properly tuned combustion engine. But we need keep in mind, that for packaging reasons this system should be compact, and for this principal reason we have several problems to design this system complexity adequate function and low cost.

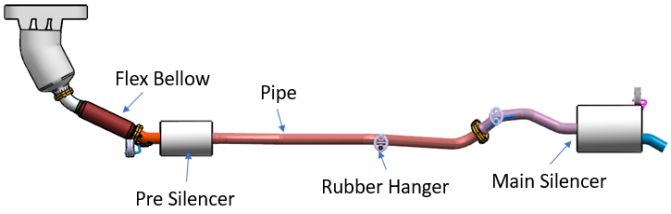

Fig -1: Exhaust System Layout

2.1. Balancing of the targets

Back pressure and NVH are the one of the critical parameter which decide the weight of the exhaust system. This is further cascade to volume distribution and pipe diameter size.

For light weight ES, we need to run below CAE analysis to arrive light weight exhaust system –

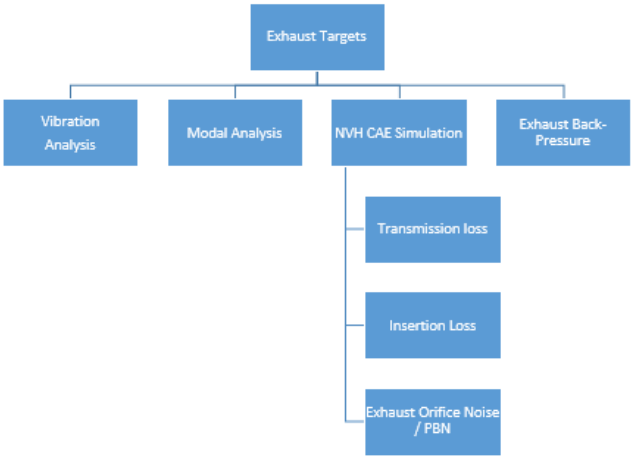

Fig. 2 Balancing of the targets

2.2. Vibration analysis

Exhaust system receives vibration from the engine and then transfers vibration to the body structure through hangers. It is important to understand exhaust system dynamic characteristics in order to reduce the vibration coming from the engine and to reduce vibration transferring to the body.

2.3. Modal Analysis

Exhaust system modes are critical for exhaust dynamic analysis. A normal modes analysis should be performed to make sure that the frequencies of the exhaust system does not line up with the frequencies of the power plant and body. Also the same analysis is helpful to determine the nodal points on the exhaust system. These nodal points can be used as the locations where hanger rods can be attached to the exhaust system. This will minimize vibrational energy transferred to the body.

Rubber hanger stiffness and no. of rod hanger is also one of the avenue for light weight exhaust system. Lesser the rod hanger, lesser the noise in incab, lesser will be cost of exhaust system.

2.4. NVH CAE Simulation

Following 3 criterions are used in the development of exhaust system for noise

A. Acoustic Transmission Loss

B. Acoustic Insertion Loss

C. Exhaust Orifice noise

Balancing the pre muffler and post muffler volume is the one of the key contributor to meet the exhaust orifice noise along with pipe diameter place major role in meeting flow noise.

Engine calibration is also the key parameter to meet the noise requirements, with change in calibration noise quality and performance gets changed.

2.5. Exhaust Back-Pressure Simulation using CFD

Computational Fluid Dynamics (CFD) simulation is required to evaluate flow performance (in terms of system pressure drop and backpressure prediction) of different concepts of Exhaust connection elbow and exhaust systems. CFD simulations are performed using appropriate commercial CFD software. CFD analysis is done at rated operating condition of the engine.

Pipe diameter and muffler expansion is the key parameter to meet back pressure requirement.

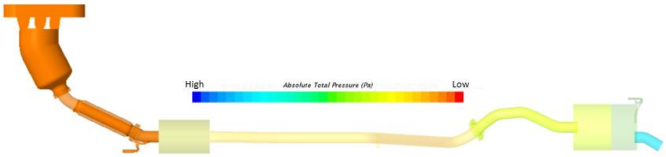

Fig -3: Exhaust Back-Pressure Simulation using CFD

3. Material Selection

Durable exhaust system design, development and manufacturing is mandated for the vehicle to be competitive and comparative. Material selection for the exhaust system plays a vital role due to the increased warranty requirements and regulatory compliances. Physical, chemical and mechanical characteristics of the materials used for conventional and special applications are compared. Exhaust system materials should possess high temperature oxidation resistance, thermo-mechanical vibration resistance, external salt corrosion resistance and internal acid/base corrosion resistances. Internal components such as inner cones, baffle plates, retainer rings, perforated pipes and external components such as hanger rod, outer shell, heat shield, end caps outer cones, flex tube, manifold etc. should be able to withstand high thermal impact and vibrations caused by road load, thermal load and engine load.

ES weight can be balance using high grade material with lesser weight thickness.

Pipe material, we need to decide based on B10 life (salt spray test and corrosion requirements) and considering the warranty targets.

4. Manufacturing Process

All the above stages combined with the packaging of the engine evolve the design of the prototype muffler and those; can be taken up for manufacturing. Following are some of the important manufacturing considerations summarized based on experience:

- There should not be any leakage of gas from one chamber to another.
- Welding process.
- Acoustic performance on manufacturing of the perforated tube.
- Tube material
- Muffler manufacturing process
- Flange type and manufacturing process.

5. Benchmarking

The first step in any design and development activity is to set a target by doing benchmarking exercise of same kind of models. The same will be applicable for the silencer here, to set a target in terms of transmission loss of same engine power models of competitor benchmarking vehicles. Based on the provided engine input data and bench mark study target for back pressure and noise range are decided.

6. New Technologies

New emerging technologies are exhaust valve resonator free pipe (RFP), exhaust valve, Helmholtz resonator same can also be explored considering the cost targets.

7. Through VE techniques

Strong performance of cost planning in the Product Development Process (PDP) - Although the company possesses an image of developing expensive products, with strong focus on quality, cost planning is increasingly present as an active parameter of the project. The PDP has three clear objectives: time, quality and cost.

- Development through multifunctional teams. The basis of the multifunctional teams involves people from the Engineering, Purchase and VE departments. This allows an exchange of knowledge to make cost reduction proposals in order to achieve the goals of target-cost. Strong coordination and cooperation among people from all departments of the company allow the maintenance of a good activity flow.
- Important function of Finance. The financial function is essential to manage target-costing. It acts to supply information that guides the activities of cost planning for the entire company, measuring and monitoring the activities to achieve the company's strategic objectives.
- Integration of cost planning with the company's global strategy. It is possible to improve the original design by developing studies with local suppliers, changing materials or production processes and simplifying the design for local needs.
- Use of tools and techniques that support VE. As described previously, VE is not applied in a systematic way to the cost reduction process to achieve the target-cost. However, it was observed that many of the cost reduction techniques used by the company, e.g., Reverse Engineering, Design for manufacturing and assembly (DFMA), Quality function deployment (QFD), modularity, part standardization, support the methodology of VE and target costing.

8. CONCLUSIONS

In this current study we explore different avenues to achieve the light weight exhaust system. The evolution of lightweight exhaust system design represents a dynamic and transformative journey that intersects cutting-edge materials science, advanced manufacturing techniques,

computational simulations, and a holistic approach to VE techniques.

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